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AN
A C C O U N T
OF SOME
THERMOMETRICAL EXPERIMENTS;

CONTAINING,

- I. Experiments relating to the cold produced by the evaporation of various fluids, with a method of purifying ether.
- II. Experiments relating to the expansion of mercury.
- III. Description of a thermometrical barometer.

By TIBERIUS CAVALLLO, F. R. S.

Who was nominated by the President and Council to prosecute Discoveries in Natural History, pursuant to the Will of the late HENRY BAKER, Esq. F. R. S.

Read at the ROYAL SOCIETY, June 28, 1781,

A N A C C O U N T, &c.

IT is at present well known, that by the evaporation of various fluids a sensible degree of cold is produced; and that by the evaporation of ether, which is the most volatile fluid we are acquainted with, water may be congealed, and the thermometer may be brought several degrees below the freezing point. But as various thermometrical experiments, which I lately made, have exhibited some new phenomena, and as I have contrived an easy and pleasing method of freezing a small quantity of water in a short time, and in every climate; I think it not improper to give an account of these things in the first part of this lecture.

My first experiments were intended to discover, if possible, a fluid cheaper than ether, by the evaporation of which a degree of cold sufficient for some useful purpose might be generated. But in this my expectation was disappointed, as I found that ether was incomparably superior to any other fluid, as the cold it produced was several degrees greater than that occasioned by any other of the most volatile fluids whatever. Being, therefore, obliged to use ether, I endeavoured to contrive a method, by which the least possible quantity of it might be wasted in the production of a degree of cold sufficient to freeze water, and in this I met with success. But before we come to the description of this method, I

shall briefly relate some observations made on the cold produced by the evaporation of other fluids besides ether.

In a room, the temperature of which was 64° according to FAHRENHEIT's thermometer, and in which the air was gently ventilated, I observed the effects produced by various fluids when thrown upon the ball of a thermometer. The ball of this thermometer was quite detached from the ivory piece upon which the scale was engraved. The various fluids were thrown upon the thermometer through the capillary aperture of a small glass vessel, shaped like a funnel, and care was taken to throw them so slowly upon the bulb of the thermometer, that a drop might now and then fall from the under part of it; except when those fluids were used, which evaporate very slowly, in which case it was sufficient to keep the ball of the thermometer only moist, without any drop falling from it. During the experiment the thermometer was kept turning very gently round its axis, in order that the fluid used might fall upon every part of its bulb. This method I find to answer much better than that of dipping the ball of the thermometer into the fluid and removing it immediately after, or that of wetting the thermometer with a feather. The evaporation, and consequently the cold produced by it, may be increased by ventilation. *viz.* by blowing with a pair of bellows upon the thermometer; but this was not used in the following experiments, because it is not easily performed by one person, and also because it occasions very uncertain results.

With the above described method I began to examine the effects of water, and found, that the thermometer was brought down to 56° , *viz.* 8° below the temperature of the room in which the experiment was made, and of the water employed.

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This effect was produced in about two minutes time, after which a larger continuation did not bring the mercury lower.

By means of spirit of wine the thermometer was brought down to 48° , which is only 16° below the temperature of the room, and of the spirit employed. When the spirit of wine is highly rectified, the cold produced by its evaporation is certainly greater than when it is of the common sort; but the difference is not so great as one, who never tried the experiment, might expect. The purer spirit produces the effect much quicker.

Using various other fluids, which were either compounds of water and spiritous substances, or pure essences, I found that the cold produced by their evaporation was generally in some intermediate degree between the cold produced by the water and that produced by the spirit of wine.

Spirit of turpentine brought the thermometer only 3° lower than the temperature of the room; but olive oil and other oils, which evaporate either very slowly or not at all, did not sensibly affect the thermometer.

Willing to observe how much electrization could increase the evaporation of spirit of wine, and consequently the cold produced by it, I put the tube containing the spirit into an insulating handle, and connected it with the conductor of an electrical machine, which was kept in action whilst the experiment was performed; by these means the thermometer was brought down to 47° . Having tried the three mineral acids I found, that instead of cooling they heated the thermometer, which effect I expected; since it is well known, that those acids attract the water from the atmosphere, and that heat is produced by the combination of water and any of them. The vitriolic acid, which was very strong and transparent, raised the

thermometer to 102° ; the smoaking nitrous acid raised it to 72° ; and the marine acid raised it to 66° ; the temperature of the room, as well as of the acids, being 64° , as mentioned above.

The apparatus which I contrived for the purpose of using the least possible quantity of ether in freezing water, &c. consists in a glass tube, terminating in a capillary aperture, which tube is to be fixed upon the bottle that contains the ether. Fig. 1. of the annexed drawing exhibits such a tube, round the lower part of which, *viz.* at A some thread is wound, in order to let it fit the neck of the bottle. When the experiment is to be made, the stopper of the bottle containing the ether is removed, and the above mentioned tube is fixed upon it. The thread round this tube should be moistened a little with water or spittle before it is fixed on the bottle, in order to prevent more effectually any escape of ether between the neck of the bottle and the tube. Then holding the bottle by its bottom FG (fig. 2.) and keeping it inclined as is shewn in the figure, the small stream of ether issuing out of the aperture D of the tube DE, is directed upon the ball of the thermometer, or upon a tube containing water or other liquor that is required to be congealed.

Ether being very volatile, and having the remarkable property of increasing the bulk of air, does not require any aperture, through which the air might enter the bottle, in proportion as the ether goes out: the heat of the hand is more than sufficient to force the ether in a stream from the aperture D.

After this manner, throwing the stream of ether upon the ball of a thermometer in such quantity as that a drop of ether might now and then, for instance every 10 seconds, fall from the under part of the thermometer, I have brought the mercury down to 3° , *viz.* 29° below the freezing point, when the
atmosphere

atmosphere was somewhat hotter than temperate, and that without blowing upon the thermometer.

When the ether is very good, *viz.* is capable of dissolving elastic gum, and the thermometer has a small bulb, not above twenty drops of ether are required to produce this effect, and about two minutes of time; but when the ether is of the common sort, a greater quantity of it, and a longer time, is necessary to be employed, though at last the thermometer is brought down very nearly as low by this as by the best sort of ether.

In order to freeze water by the evaporation of ether, I take a thin glass tube about four inches long and about one-fifth of an inch in diameter, hermetically closed at one end, and put a little water in it, so as to fill about half an inch length of it, as is shewn at CB in the figure. Into this tube a slender wire H is also introduced, the lower extremity of which is twisted in a spiral manner, and serves to draw up the ice, when formed. Things being thus prepared, I hold the glass tube by its upper part A with the fingers of the left hand, and keep it continually and gently turning round its axis, first one way, and then the contrary; whilst with the right hand I hold the phial containing the ether in such a manner as to direct the stream of ether on the outside of the tube, and a little above the surface of the water in it. The capillary aperture D should be kept almost in contact with the surface of the tube that contains the water. Continuing this operation for two or three minutes, the water will be froze as it were in an instant; since it will appear to become opaque at the bottom B, and the opacity will ascend at C in less than half a second of time, which exhibits a beautiful appearance. This congelation, however, is only superficial, and in order to congeal the whole quantity of water,

ter, the operation must be continued one or two minutes longer; after which the wire H will be found to be kept very tight by the ice. Now the bottle with the ether is left upon a table or other place, and to the outside of the glass tube the hand must be applied for a moment, in order to soften the surface of the ice, which adheres very firmly to the glass, and then pulling the wire H out of the tube, a solid and hard piece of ice will come out, fastened to its spiral extremity.

Instead of the wire H sometimes I put a small thermometer into this tube so as to have its bulb immersed in the water. With this thermometer I have observed a very remarkable phenomenon, which seems to be not explicable in the present state of knowledge concerning heat and cold. This is, that water will freeze in the winter with a less degree of cold than it will in the summer, or when the weather is hotter: for instance, in the winter the water in the tube AB will freeze when the thermometer is about 30° ; but in the summer, or even when the temperature of the atmosphere is about 60° , the quicksilver in the thermometer must be brought ten or fifteen, or even more, degrees below the freezing point, before the water which surrounds the said thermometer will be converted into ice, even superficially; hence it appears, that in the summer time a greater quantity of ether and longer time is required to freeze a given quantity of water than in the winter, not only because then a greater degree of heat is to be overcome, but principally because in the summer a much greater degree of cold must be actually produced before the water that is kept in it will assume a solid form. When the temperature of the atmosphere has been about 40° , I have froze a quantity of water with an equal weight of good ether, but at present,

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being summer, between two and three times the quantity of the same ether must be used to produce the same effect.

There seems to be something in the air which, besides heat, interferes with the freezing of water, and perhaps of all fluids, though I cannot say from experience whether the above mentioned difference between the freezing of water in winter and summer, takes place with other fluids, as milk and other animal fluids, oils, wines, &c.

The proportion between the quantity of the ether and of the water that may be frozen by it, seems to vary according to the quantity of water; for a larger quantity of water seems to require a proportionably less quantity of ether than a smaller quantity of water, supposing that the water is contained in cylindrical glass vessels; for I have not tried whether a metal vessel instead of a glass one, and whether some other shape besides the cylindrical, might not facilitate the congelation. In the beginning of the spring I froze about a quarter of an ounce of water with nearly half an ounce weight of ether, the apparatus being larger, though similar to that described above.

Now as the price of ether, sufficiently good for the purpose, is generally between eighteen pence and two shillings *per* ounce, it is plain, that with less than two shillings a quarter of an ounce of ice, or ice cream, may be made in every climate, and at any time, which may afford great satisfaction to those persons, who living in places where no natural ice is to be had, never saw or tasted any such delicious refreshments.

When a small piece of ice, for instance, of about ten grains in weight, is wanted, the necessary apparatus is very small, and the expence of the ether not worth mentioning. I have a small box, which is four inches and a half long, two inches broad, and one inch and a half deep, which contains all the apparatus

ratus necessary for this purpose, *viz.* a bottle capable of containing about one ounce of ether, two pointed tubes (in case that one should break) a tube in which the water is to be frozen, and the wire. With the quantity of ether contained in this small and very portable apparatus, the experiment, when carefully performed, may be repeated about ten times. A person who wishes to perform such experiments in hot climates, and in places where ice is not easily procured, requires only a large bottle of ether, besides the small apparatus described above.

It is a known fact, that the moment a quantity of water becomes ice, a thermometer kept immersed in it, rises a few degrees, and accordingly this is observed in our experiment, *viz.* the mercury of the thermometer, which is immersed in the water of the tube AB, will suddenly rise, sometimes as much as ten degrees, when the water becomes first opaque. Electrization increases very little the degree of cold produced by the evaporation of ether. Having thrown the electrified, and also the unelectrified, stream of ether upon the bulb of a thermometer, the mercury in it was brought down two degrees lower in the former than in the latter case.

As various persons may, perhaps, be induced by this paper to repeat such experiments, and as ether is a fluid which can with difficulty be preserved, it may be useful to mention, that a cork confines ether in a glass bottle much better than a glass stopple, which it is almost impossible to grind so well as intirely to prevent the evaporation of ether. When a stopple, made very nicely out of a uniform and close piece of cork, which goes rather tight, is put upon a bottle of ether, the smell of that fluid cannot be perceived through it; but I never saw a glass stopple that could produce the same effect. By opening
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ing the bottle very often, or by long keeping, the cork becomes loose, in which case it must be changed; and thus ether, spirit of wine, or any fluid, excepting those which corrode cork, may be preserved.

I shall now describe a method of purifying vitriolic ether, which is very easy and expeditious, though not very profitable: this method I learned of Mr. WINCH, Chemist, in the Hay-market. Fill about a quarter of a strong bottle with common ether, and upon it pour about twice as much water, then stop the bottle, and give it a shake, so as to mix for a time the ether with the water. This done, keep the bottle without motion, and with the mouth downwards, till the ether is separated from the water and swims over it, which requires not above three or four minutes of time; then open the bottle, and keeping it still inverted, let the greatest part of the water come out very gently; after this the bottle being turned with the mouth upwards, more water must be poured in it, and in short the same operation must be repeated three or four times. Lastly, all the water being separated from the ether by decanting it with dexterity, the ether will be found to be exceedingly pure. By this means I have purified common vitriolic ether, which could not affect elastic gum, and have reduced it into such a state as that elastic gum was easily dissolved by it. Indeed this purified ether appeared by every trial to be purer than I ever saw it, even when made after the best usual method, and in the most careful manner. The only inconvenience attending this process is, that a vast quantity of ether is lost. Not above three or four ounces of a pound of common ether remain after the purification. As the greatest part of the ether is certainly mixed with the water that is used in the process, it may perhaps be worth while to put that water into a retort, and

to distil the ether from it, which must come sufficiently pure for common use.

It is commonly believed, that water combines with the purest part of ether, when those two fluids are kept together; whereas, by the above described process, the contrary is established: perhaps when ether is kept in contact with water for a long time, the purest part of it may appear to be lost, because the ether may be combined with, and may retain some water in itself, at the same time that the water combines with and retains some ether, whereas the case may be different when the ether is quickly washed in water, and is immediately after separated from it: but in respect to this I have yet not made any experiments, so as to be able to decide the matter.

II. *Experiments relating to the expansion of mercury.*

THE difficulty and uncertainty attending the various methods hitherto proposed for investigating the expansion of quicksilver, or its increase of bulk when rarified by a given degree of heat, determined me to contrive some method by which this purpose might be effected with more certainty and precision. After various experiments I hit upon the following method, which to me seems both new and capable of great accuracy, though in this I may be deceived.

First, having blown a ball to a capillary tube, such as are commonly used for thermometers, I weighed it, and found that this empty thermometer was equal to 79,25 grains. This empty glass previous to its being weighed was rendered as perfectly

fectly clean as possible, which is a necessary precaution in this experiment, which depends upon a very great accuracy of weight. Then I introduced some mercury into the stem of this thermometer, taking care that none of it entered the ball, and, by adapting a scale of inches to the tube, observed that 4,3 inches length of the tube was filled with the mercury. The thermometer was now weighed again, and from this weight, the weight of the glass found before being subtracted, the remainder, *viz.* 0,24 gr. shewed the weight of so much quicksilver as filled 4,3 inches of the tube. Now the ball of the thermometer, and also part of the tube, were intirely filled with quicksilver: then, in order to find out the weight of the mercury contained in it, the thermometer was weighed for the last time, and from this weight the weight of the glass being subtracted, the remainder, *viz.* 3205 grs. shewed the weight of the whole quantity of quicksilver contained in the thermometer.

By comparison with a graduated thermometer in hot and cold water, I made a scale to the new thermometer according to FAHRENHEIT's, and by applying a scale of inches found, that the length of 20° in this scale was equal to 1,33 inch. But 0,24 gr. was the weight of so much mercury as filled 4,3 inches length of the tube; therefore, by the rule of proportion it will be found, that the weight of so much quicksilver as fills 1,33 inch of the tube, *viz.* the length of 20° is equal to 0,0742 gr. nearly, and that the weight of so much quicksilver as fills the length of the tube that is equivalent to one degree, is equal to 0,00371 gr. Now it is clear, that the weight of the whole quantity of quicksilver contained in the thermometer is to the weight of so much quicksilver as fills the length of one degree in the tube, as the bulk of the whole quantity of quick-

silver in a given degree of heat, to the increase of bulk, that the same whole quantity of quicksilver acquires when heated of but 1° ; viz. 32,05 grs. is to 0,00371 gr. as 1 is to 0,0011 + ; so that by this experiment it appears, that 1° of FAHRENHEIT's thermometer increases the bulk of mercury not above $\frac{1}{800}$ th parts. In this process a small deviation from mathematical exactness is occasioned by the small difference of weight between the quicksilver of the tube when first weighed and when it is afterwards heated to 1° ; but by an easy calculation it will be found, that this difference is so exceedingly small as not to be perceived by our exactest weighing and measuring instruments.

For clearness sake I shall subjoin the calculation of the above related experiments, disencumbered from words. Here the decimals are not computed to a very large number, that being unnecessary for this purpose.

Weight of the glass,	-	-	-	-	79,25 grs.
Weight of so much quicksilver as filled 4,3 inches					
length of the tube,	-	-	-	-	0,24 grs.
Weight of the whole quantity of quicksilver con-					
tained in the thermometer,	-	-	-	-	32,05 grs.
Length of the tube equal to 20° ,	-	-	-	-	1,33 inch.

$$4,3 : 0,24 :: 1,33 : 0,0742 = 20^{\circ}$$

$$20^{\circ} : 0,0742 :: 1 : 0,00371$$

$32,05 : 0,00371 :: 1 : 0,00011 + =$ to the expansion occasioned by one degree of heat.

Having repeated this experiment with other thermometers, and by similar calculations, each process gave a result little different from the others, which irregularity is certainly owing to the imperfection of my scales, which are not of the nicest sort: but taking a mean of various experiments it appears, that

that 1° of heat, according to FAHRENHEIT's thermometer, increases the bulk of a quantity of quicksilver of $\frac{1}{1000000}$ th parts, viz. if the bulk of a quantity of quicksilver in the temperature of 50° is equal to 100,000 cubic inches, the bulk of the same quantity of quicksilver in the temperature of 51° will be equal to 100,009 cubic inches.

It is almost superfluous to mention, that the cavity of the tubes employed for these experiments, must be perfectly uniform throughout. The scales to be used for this method should be so exact as to be turned by the hundredth part of a grain when charged with about half an ounce weight.

From these observations the method of graduating, or of determining the length of a degree in a new thermometer, is easily deduced, the only requisites for the calculation being the weight of a quantity of quicksilver, which fills a known length of the tube, and the weight of the whole quantity of quicksilver contained in the thermometer when filled. Suppose, for instance, that in making a new thermometer it be found, that the weight of so much quicksilver as fills five inches length of the tube is equal to ten grains, and that the weight of the whole quantity of quicksilver contained in the thermometer weighs 300 grains. It is plain, that if the whole quantity of quicksilver weighs 300 grs. $\frac{1}{1000000}$ th parts of it must weigh 0,027 gr. But the weight of so much mercury as fills five inches of the tube is equal to 10 grains; therefore, 0,027 gr. weight of quicksilver must fill 0,0133 inch of the tube, and this is equal to the length of 1° , or the double, treble, &c. of it is equal to two, three, &c. degrees.

By this means the scale may be made; that is, it may be divided into degrees, but the numbers cannot be added to them without finding which of those degrees corresponds with the

freezing point or boiling point. Either the point of boiling or freezing may be found by experiment, or any other point may be ascertained by comparison with another thermometer, and then the other degrees are nominated accordingly.

III. *Description of a thermometrical barometer.*

THE determination of the various degrees of heat shewn by boiling water under different pressures of the atmosphere, has been attempted by various persons, but it was lately completed by the accurate and numerous experiments of Sir GEORGE SHUCKBURGH, member of this Society. His valuable paper is inserted in the LXIXth vol. of the Phil. Trans. Upon considering this paper, I thought it possible to construct a thermometer with proper apparatus, which, by means of boiling water, might indicate the various gravity of the atmosphere, *viz.* the height of the barometer. This thermometer, together with the suitable apparatus, might, I thought, be packed into a small and very portable box, and I even flattered myself, that with such an instrument the heights of mountains, &c. might perhaps be determined with greater facility than with the common portable barometer. My expectations are far from having been disappointed, and although the instrument which I have hitherto constructed has various defects, I have, however, thought of some expedients which will undoubtedly render it much more perfect; I shall then present to this Society a more particular account of it, and also of the experiments which I intend to make with it. The instrument in its present state consists of a cylindrical tin vessel, about two inches in diameter and five inches high, in which vessel the water is

Fig. 1.

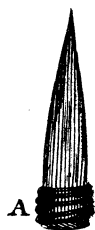
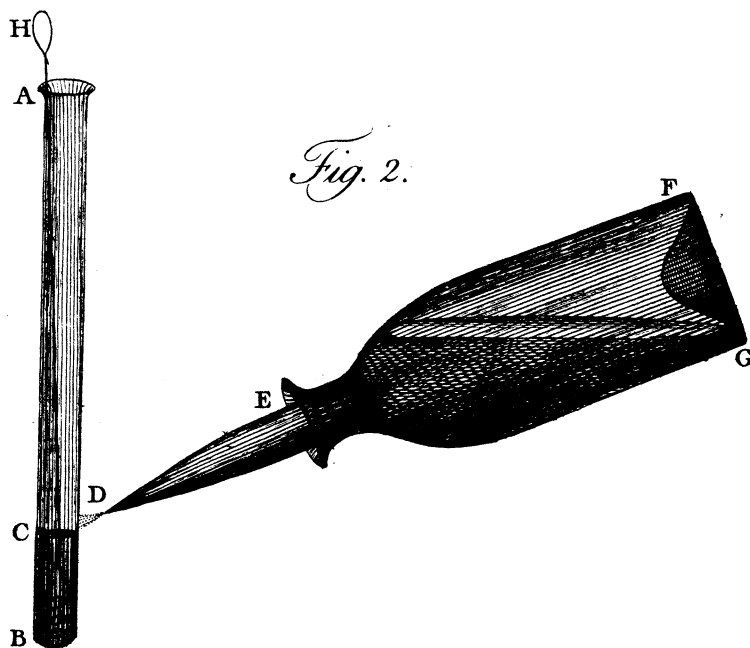


Fig. 2.



contained, which may be made to boil by the flame of a large wax candle. The thermometer is fastened to the tin vessel in such a manner as that its bulb may be about one inch above the bottom. The scale of this thermometer, which is of brass, exhibits on one side of the glass tube a few degrees of FAHRENHEIT's scale, viz. from 200° to 216° . On the other side of the tube are marked the various barometrical heights, at which the boiling water shews those particular degrees of heat which are set down in Sir G. SHUCKBURGH's table. With this instrument the barometrical height is shewn within one-tenth of an inch. The degrees of this thermometer are somewhat longer than one-ninth of an inch, and consequently may be subdivided into many parts, especially if a nonius is used. But the greatest imperfection of this instrument arises from the smallness of the tin vessel, which does not admit a sufficient quantity of water: and I find, that when a thermometer is kept in a small quantity of boiling water, the quicksilver in its stem does not stand very steady, sometimes rising or falling even half a degree; but when the quantity of water is sufficiently large, for instance is ten or twelve ounces, and is kept boiling in a proper vessel, its degree of heat under the same pressure of the atmosphere is very settled.

